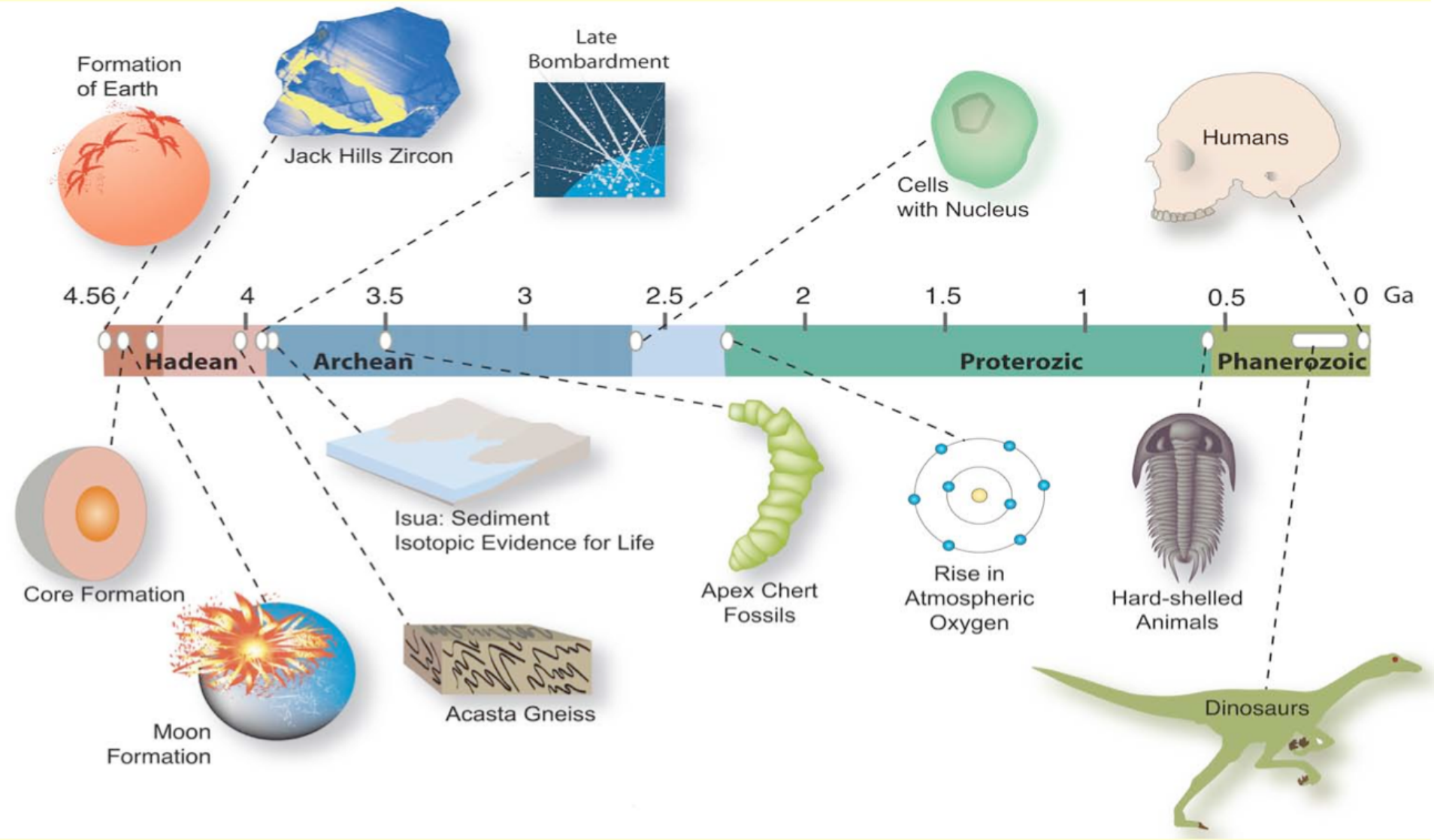
Dinosaurs, Asteroid Impacts, and Life on Earth

Warren Wiscombe

NASA Goddard



Andrée Valley

Major biological events in Earth's history

4.3 bya: Moon created, stabilizes climate

4.2-3.9 bya: Late Heavy Bombardment (comets bring water)

3.8 to 4 bya: single-cell life appears (??)

2.7 bya: cells with nuclei

2.2 bya: O2 starts to take over atmosphere

1 bya: multi-celled life

700-600 mya: Snowball Earth events

500-400 mya: life moves onto land

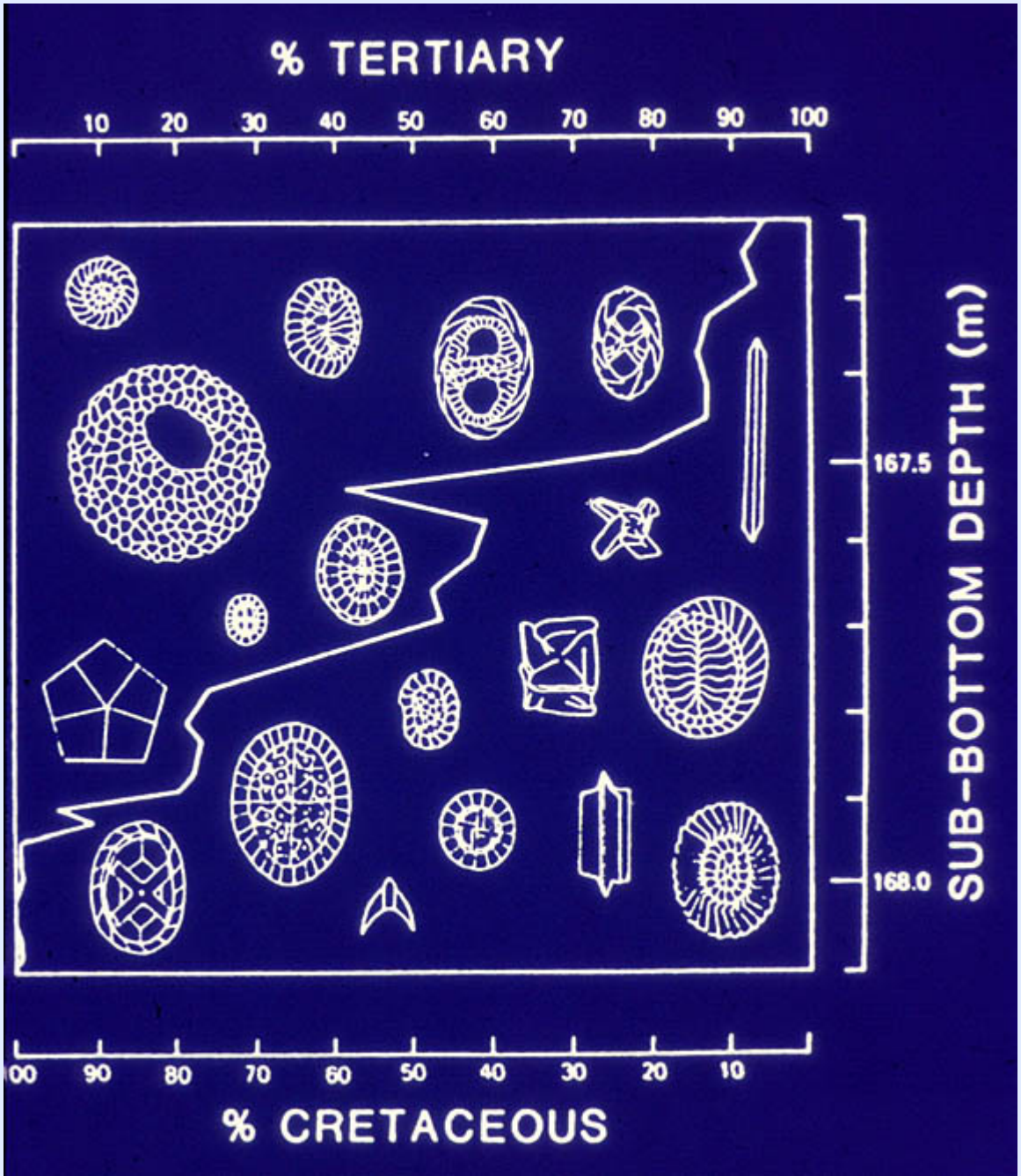
5 mass extinctions: 250 & 65 mya best known

150-65 mya: dinosaurs rule; O2 as low as 6%

(Note: individual species rarely last more than 10 my)

Movie: Peekskill_Meteorite-1992.mpg

Fossil plankton at K-T boundary



The Story of Avarez pere and Alvarez fils

Walter Alvarez, a geologist, was doing field work on the K-T boundary (65 Ma) in 1980 in Gubbio, Italy.

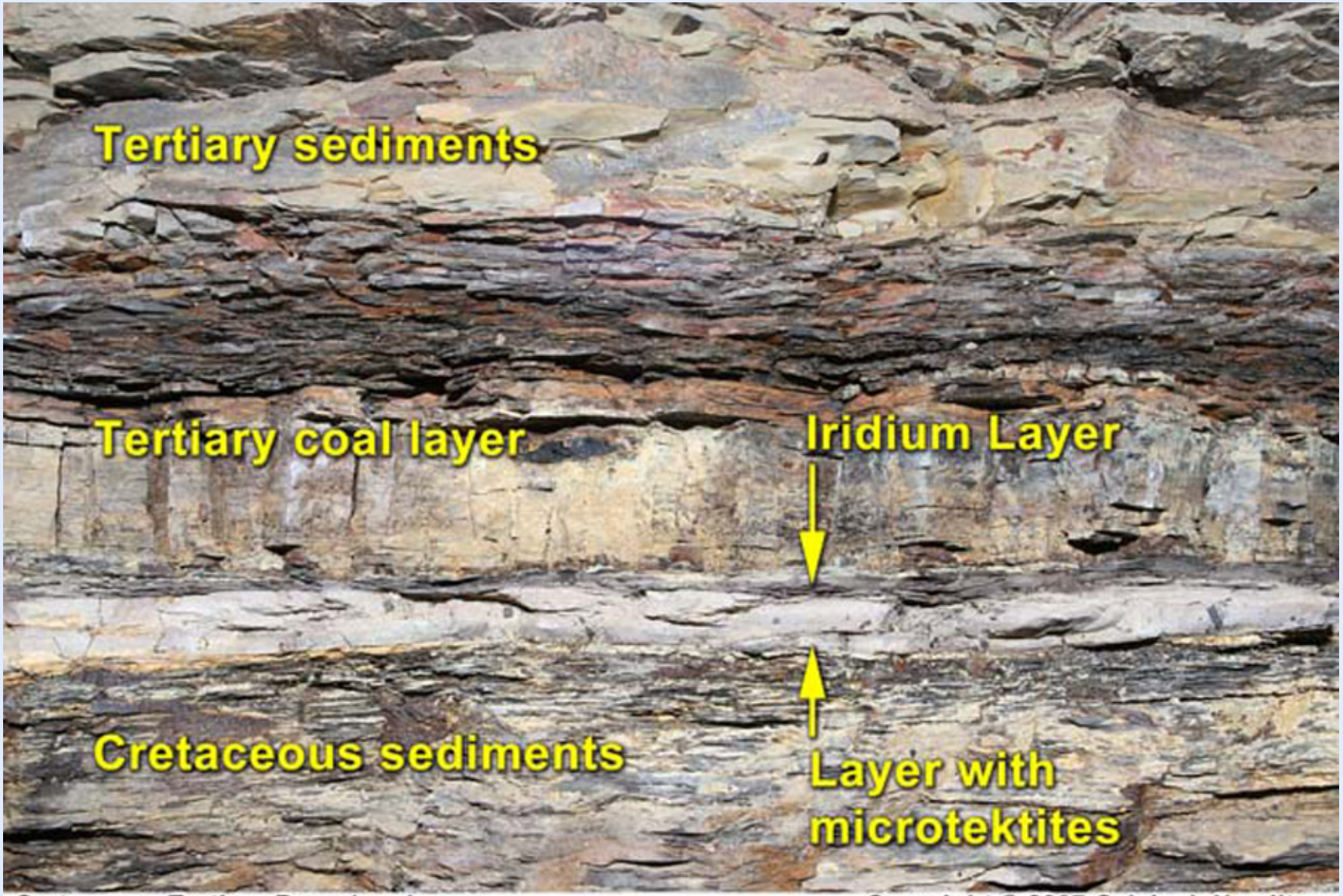
Was curious how much time the thin clay layer at the boundary represented.

He wanted absolute dates and deposition rates; fossils no use -- too irregular.

Radiometric dating not precise enough to date closely spaced points in the layer.

He hit on a way: look at meteor dust deposition.

Evidence for K-T impact found in New Mexico



Cretaceous-Tertiary Boundary Layer

Solved equation for meteorite dust deposition

% meteoritic dust = (rate of meteoritic dust fall) / (rate of normal sedimentation)

or:

rate of normal sedimentation =

(rate of meteoritic dust fall) / (% meteoritic dust)

Estimated numerator from dust fall in marine sediments far from continents.

Measured the denominator. But this is tricky. Nobelist father Luis suggested measuring iridium as a proxy for the % of meteoritic particles.

Cretaceous-Tertiary Boundary

First identified (1980) by rare metal iridium.

Global boundary layer contains record of extinction event.

Alvarez's found huge spike in iridium

(10 ppb compared to 0.3 ppb above & below K-T layer).

Discovery published in 6 Jun 1980 Science article, 14 pp long!! Also showed iridium anomalies from Denmark and New Zealand.

Four diff. methods gave asteroid size from 6 to 10 km.

Sent 60x asteroid volume as dust into atmosphere, blocking sunlight and stopping photosynthesis.

- (sulfur also)
- firestorms and soot layer

Went to great pains to refute supernova

Sites of iridium anomalies: K-T boundary (Alvarez)

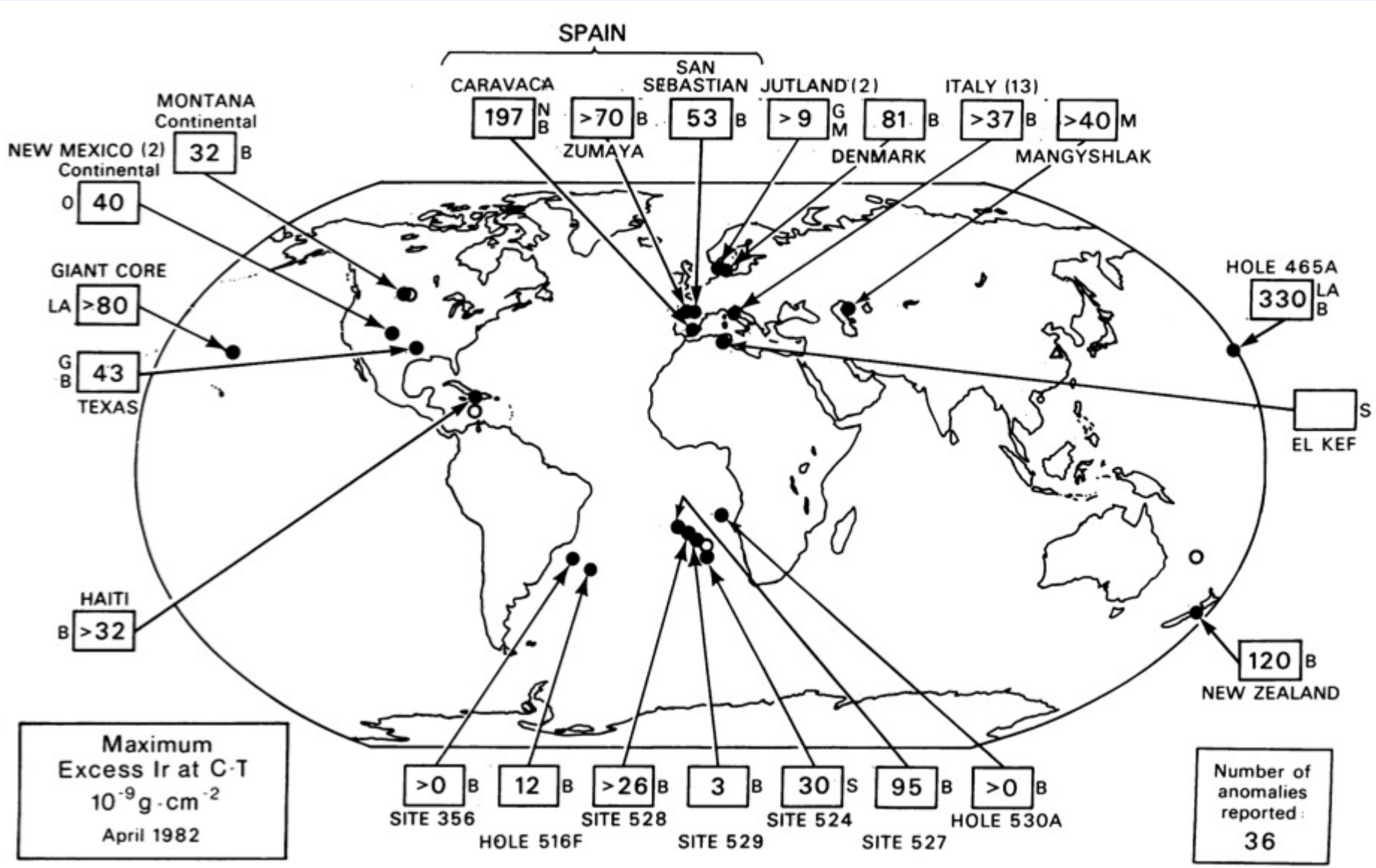
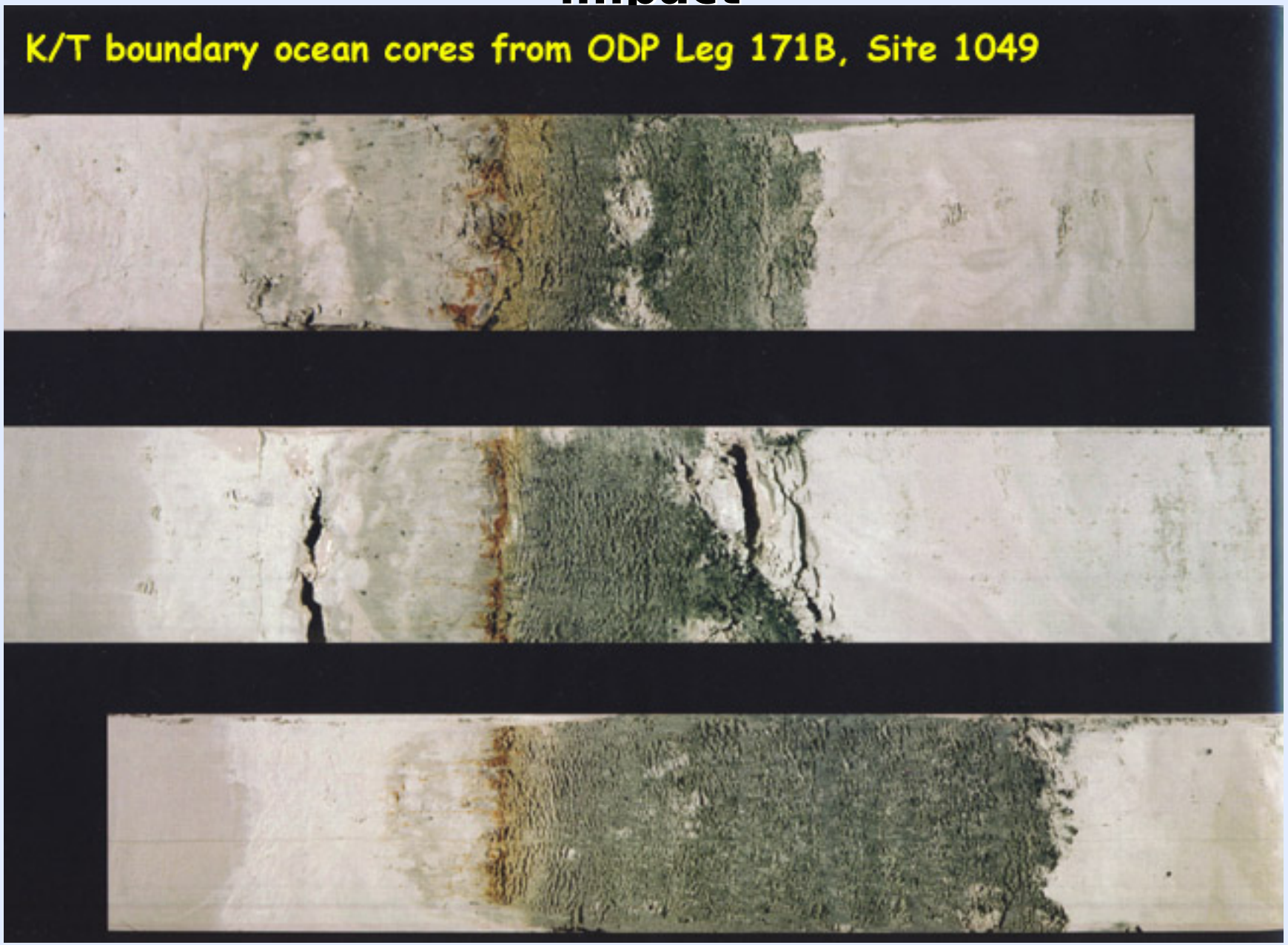


FIG. 7. Map of the world with locations of iridium anomalies. Laboratories: B, Berkeley; LA, University of California at Los Angeles; O, Los Alamos; G, Ganapathy (Baker, Co.); S, Swiss group; N, Netherlands; M, Moscow.

Ocean cores have distinct fingerprint of K-T impact



But where was the crater?

Mexican oil geologists discovered it before 1980.

They wrote to Luis Alvarez but he never replied.

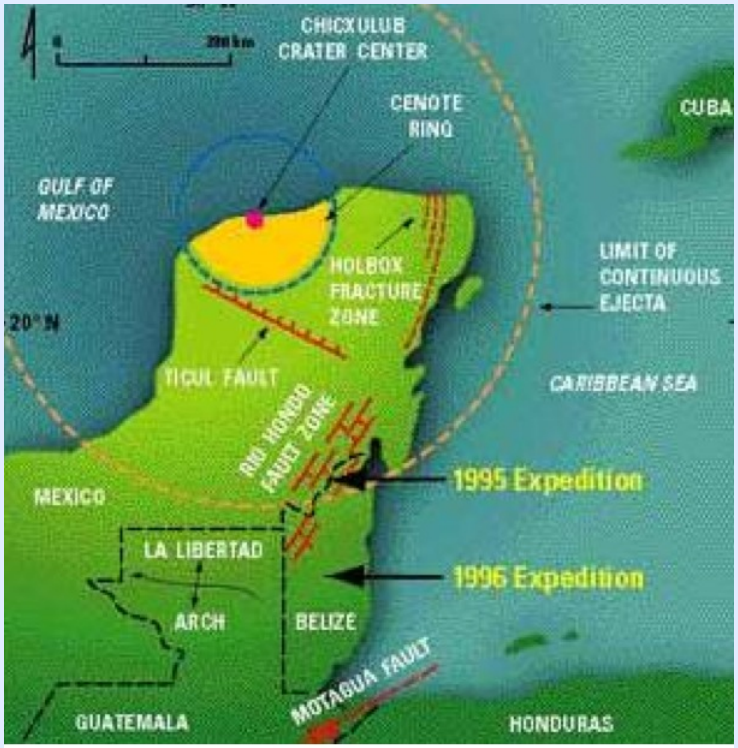
So it took another decade to re-discover it.

On the Yucatan Peninsula.

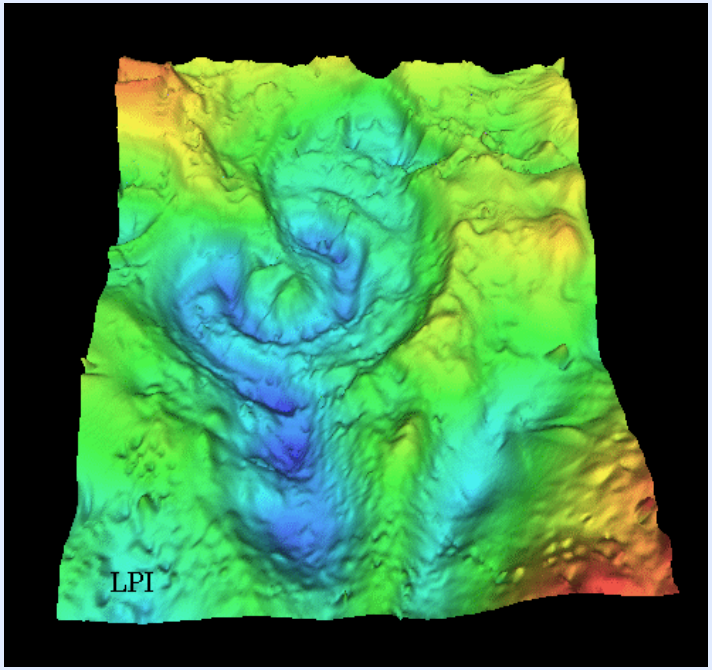
Which remains a very strange place to this day.

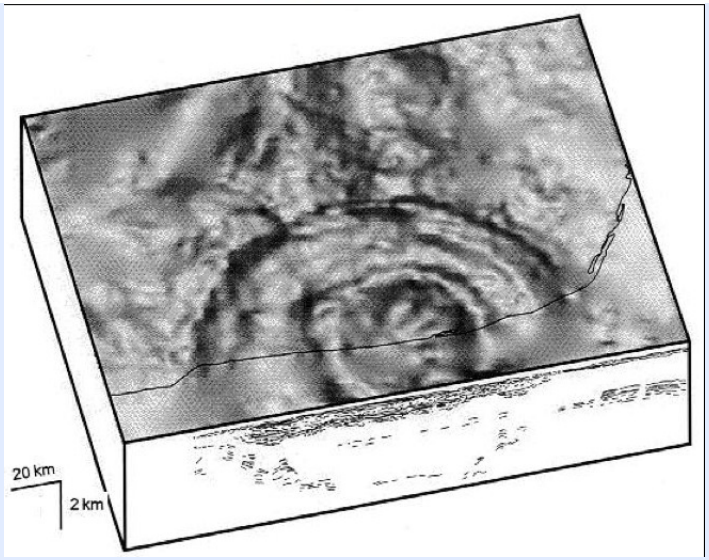
Cenote ring marks part of crater.

Chicxulub Crater, 65 Ma, 200 km wide

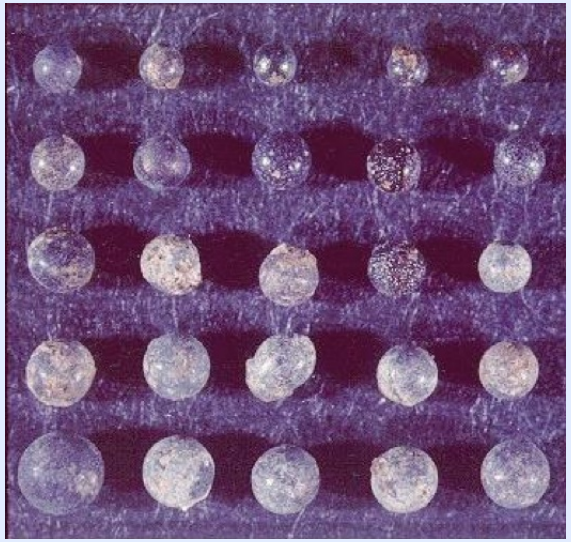


from gravity & magnetic meas'ts





from seismic reflection



tektites from Wyoming

Sidebar: "Uniformitarianism"

During 17th & 18th centuries, catastrophism (e. g. Noah's flood) held sway; postulates that Earth's landscapes were created mainly by catastrophes.

Uniformitarianism: the physical, chemical, and biological laws that operate today have also operated in the geologic past ("the present is the key to the past")

- James Hutton, late 1700s
- a fundamental principle of modern geology & paleontology

Hutton argued that processes acting slowly, over long spans of "deep time", could produce effects as large as catastrophic events.

Uniformitarianism was vigorously defended

Paleontologists fought hard to keep impacts out!

1964: Geologists only admitted 5-6 impact craters on Earth (Moon craters thought to be volcanic)

Several distinguished scientists had proposed catastrophic causes for mass extinctions:

- e.g., Harold Urey, 1973, Nobelist: several extinctions of past 40-50 Ma due to comets (cited tektites)
- All ignored!

Eugene Shoemaker was the tenacious pioneer who opened everyone's eyes to impacts, both on Earth and the Moon.

Alvarez book: T. Rex and the Crater of Doom (1997)

Chicxulub opened minds to catastrophic causes

Game was afoot to find other impacts associated with other great extinctions

- Permian Extinction (250 mya)?
- Younger Dryas Extinction (of megafauna on N. America and possibly earliest people) – airburst comet?
- Nemesis the Death Star, and periodic extinctions every 26M yr (Raup & Sepkoski, 1980s)?

Accurate physical and chemical methods to ID craters were developed, meanwhile aerial and space photography revealed many impact craters.

~178 impact craters have been ID'd; width to 300 km

If no erosion, Earth would look like Moon

Catastrophic events on early Earth

Collision with a Mars-size object (Thea) creating disk of rubble around Earth which condensed into Moon

Late Heavy Bombardment (4.2 to 3.9 Ba), perhaps due to Jupiter and Saturn migrating to their final orbits and slinging comets and/or asteroids into inner solar system

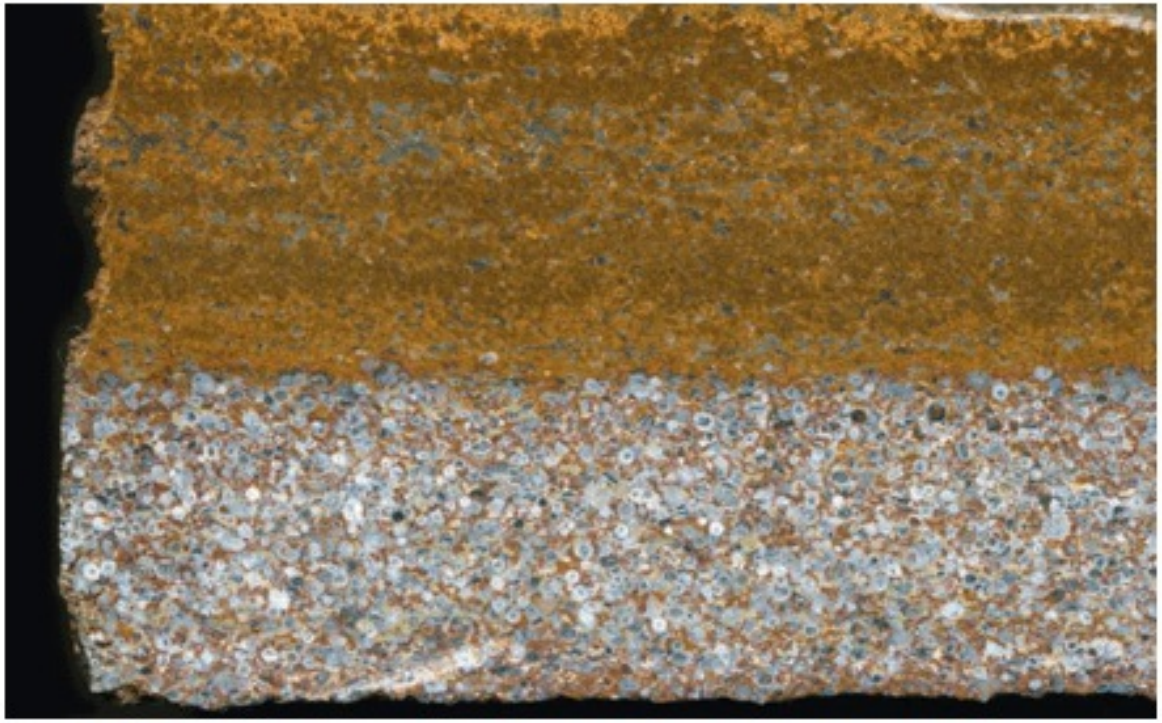
- (Moon still bears the scars of that bombardment)
- bombardment may have lasted to 2.6 Ba (every 40M yr)
- larger impactors may have boiled off oceans

Up to half of Earth's current surface water may be from comets

From 3.8 to 2.5 mya (Archean)

Asteroid Model Shows Early Life Suffered a Billion-Year Battering

Science 15 April 2011:
vol. 332 no. 6027 302-303



Big splat.

A huge impact 2.54 billion years ago deposited this centimeter-thick layer of whitish spherules—crystallized droplets of molten rock.

maybe why it took life so long to evolve past single cells

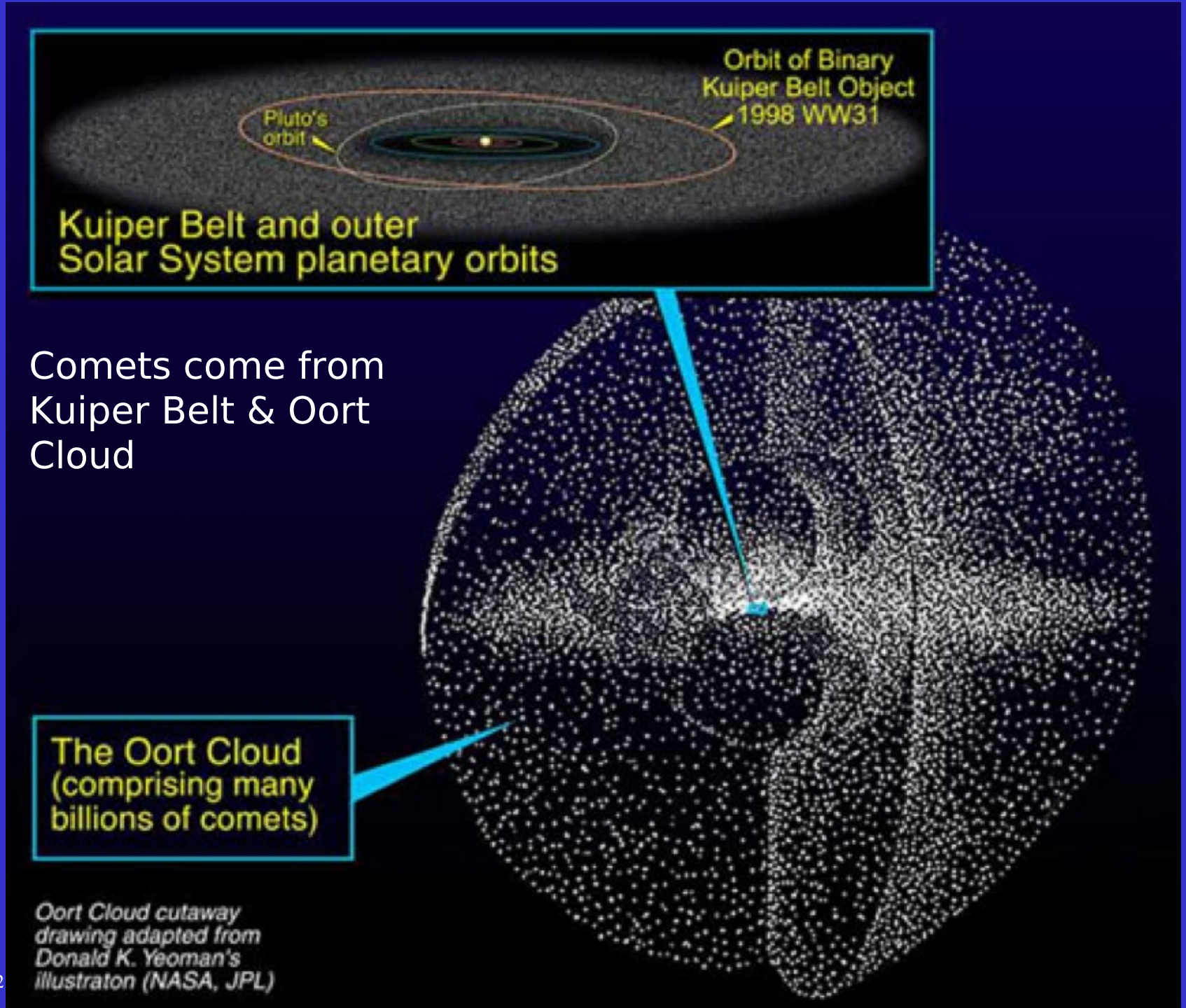
Achaean bombardment (3.9 to 2.6 Ba)

~ every 40M yr

K-T impact only one in last 500 Ma that produced such spherules.

Theory & computer simulation: Jupiter and Saturn, migrating inward, scattered asteroids out of a now-missing inner band of the Asteroid Belt.

Many scattered into sharply tilted orbits, forming group called “Hungaria Asteroids” which could have pummeled Earth.


Orbit of Binary
Kuiper Belt Object
1998 WW31
Pluto's
orbit
Kuiper Belt and outer
Solar System planetary orbits
Comets come from
Kuiper Belt & Oort
Cloud
The Oort Cloud
(comprising many
billions of comets)
Oort Cloud cutaway
drawing adapted from
Donald K. Yeoman's
illustraton (NASA, JPL)

Earth-crossing asteroid sources

Asteroids come mainly from the Asteroid Belt between Mars and Jupiter

The gravity of Jupiter and Mars perturbs the asteroids and slings some at Earth

Asteroid collisions can also sling one at Earth

Asteroids crash into each other -- 2010

- tail from ~Feb 2009 collision
- asteroid P/2010 A2 (white dot, inset)
- diam ~120 m

Hubble image, Jan 2010

Snodgrass, C. et al., 2010: A collision in 2009 as the origin of the debris trail of asteroid P/2010 A2, Nature 467, 814-816.

Earth-crossing comet sources

Kuiper Belt: 35-55 AU, beyond orbit of Neptune

more than 1300 Kuiper Belt objects found since 1992

source of short-period comets (< 200 yr)

Oort Cloud: 5000 AU ++

Comets thrown at Earth by galactic perturbations (passing stars, gas clouds, ...)

Long-period (maybe one trip only)

Comets have up to 50 times the specific energy of asteroids !

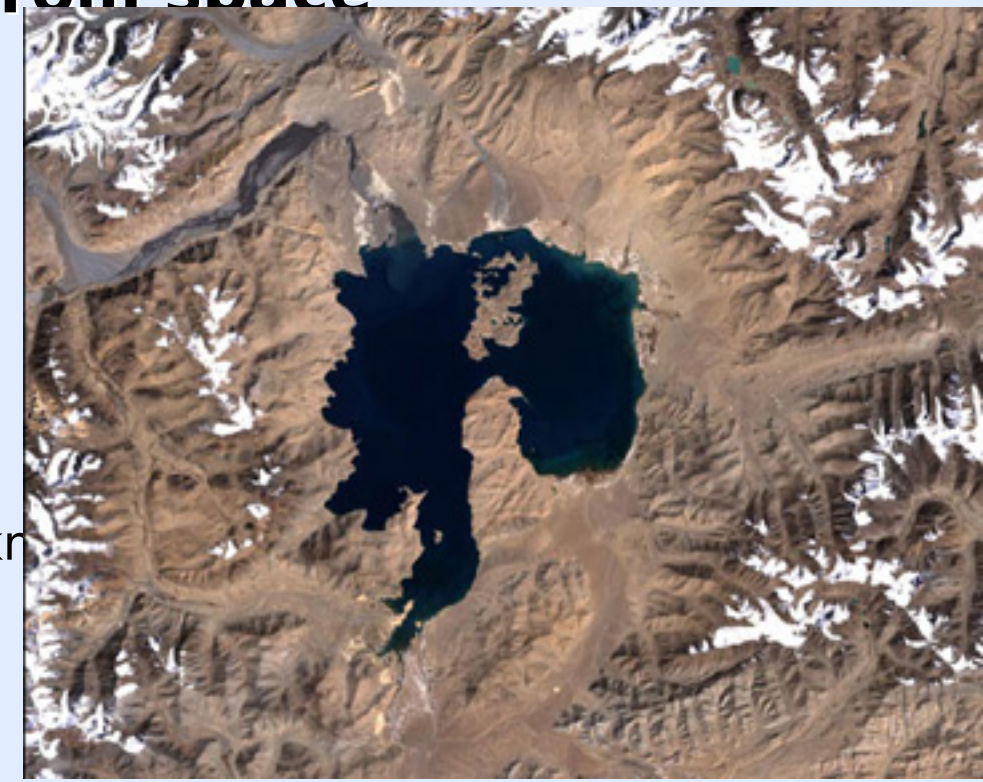
Tunguska comet, 1927: airburst 5-10 km up

tens of m in size; blast 2000 km^2; 1000x Hiroshima

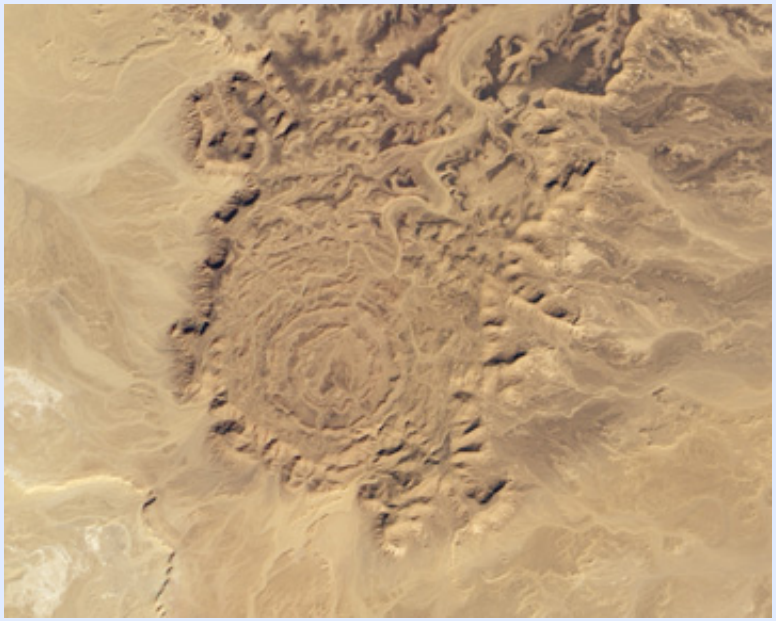
Tunguska comet, 1927: 80M trees knocked down

~178 impact craters have now been identified, most from space

Gosses Bluff, Australia (142 mya, 25 km



Kara-Kul, Tajikistan (25 mya, 45 km



Tin Bider Crater-Algeria (~70 mya, 6 km

Earth Impact Database website

Impact Structures

http://www.passc.net/EarthImpactDatabase/Agesort.html

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The Explorer's Guide to Impact Cr... | Impact Structures

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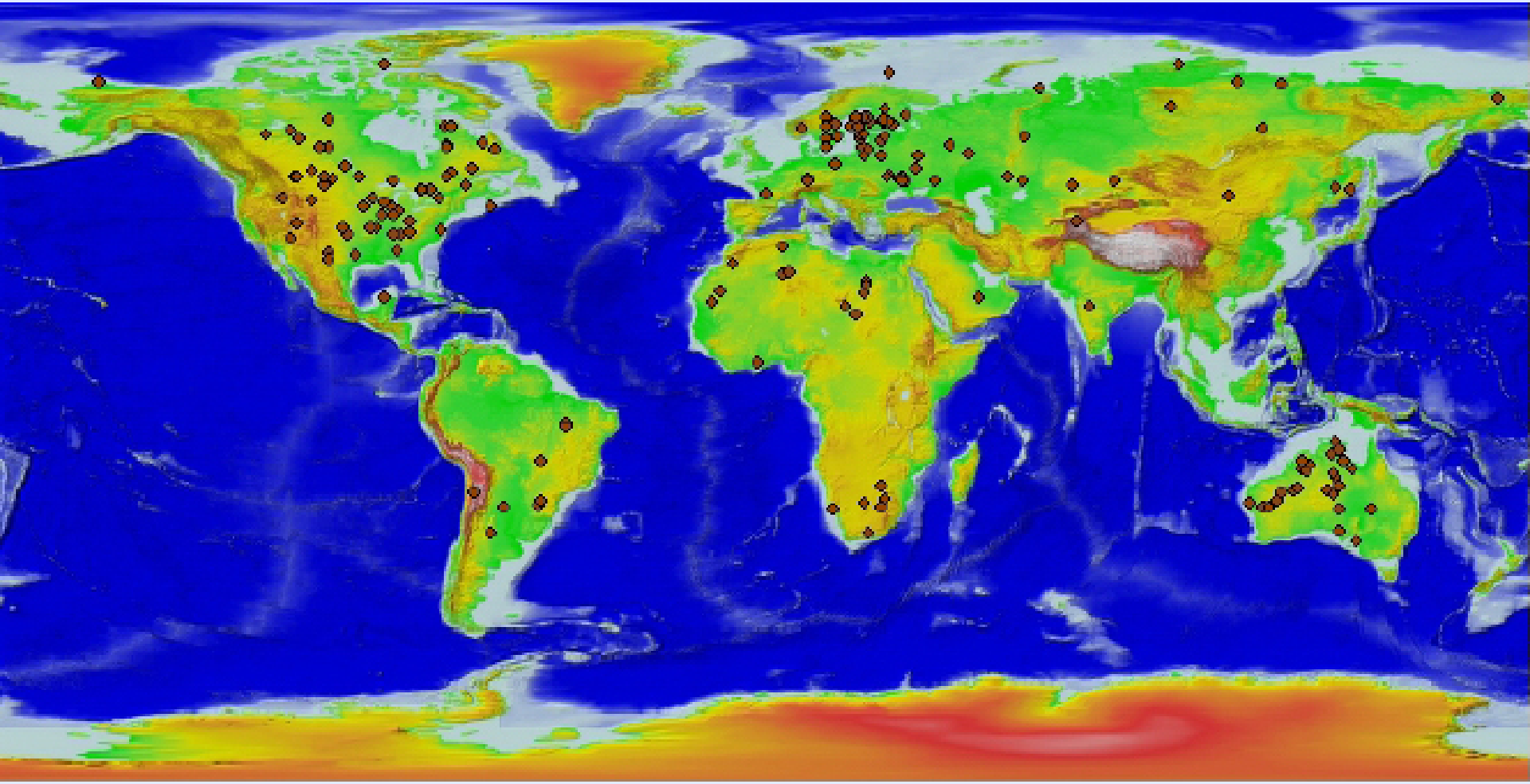
Earth Impact Database

Locations of 178 confirmed impact craters



“Confirmation” = convincing details of shock metamorphic features, associated shatter cones, or other similarly unambiguous evidence

The biggest confirmed impact crater: Vredefort Dome, South Africa

300 km, 2 Ba (2nd oldest)

asteroid ~10 km

only recognized 1990s

Only see remains of central dome (70 km), as in Moon crater below; rest is eroded

Evidence for Vredefort impact: impact breccia

granite exposed here was 7-10 km below surface when impact occurred !

Manicouagan Crater - 212 mya - 100 km wide
(close to Triassic-Jurassic mass extinction)

Twin impacts: Clearwater Lakes, Northern Canada

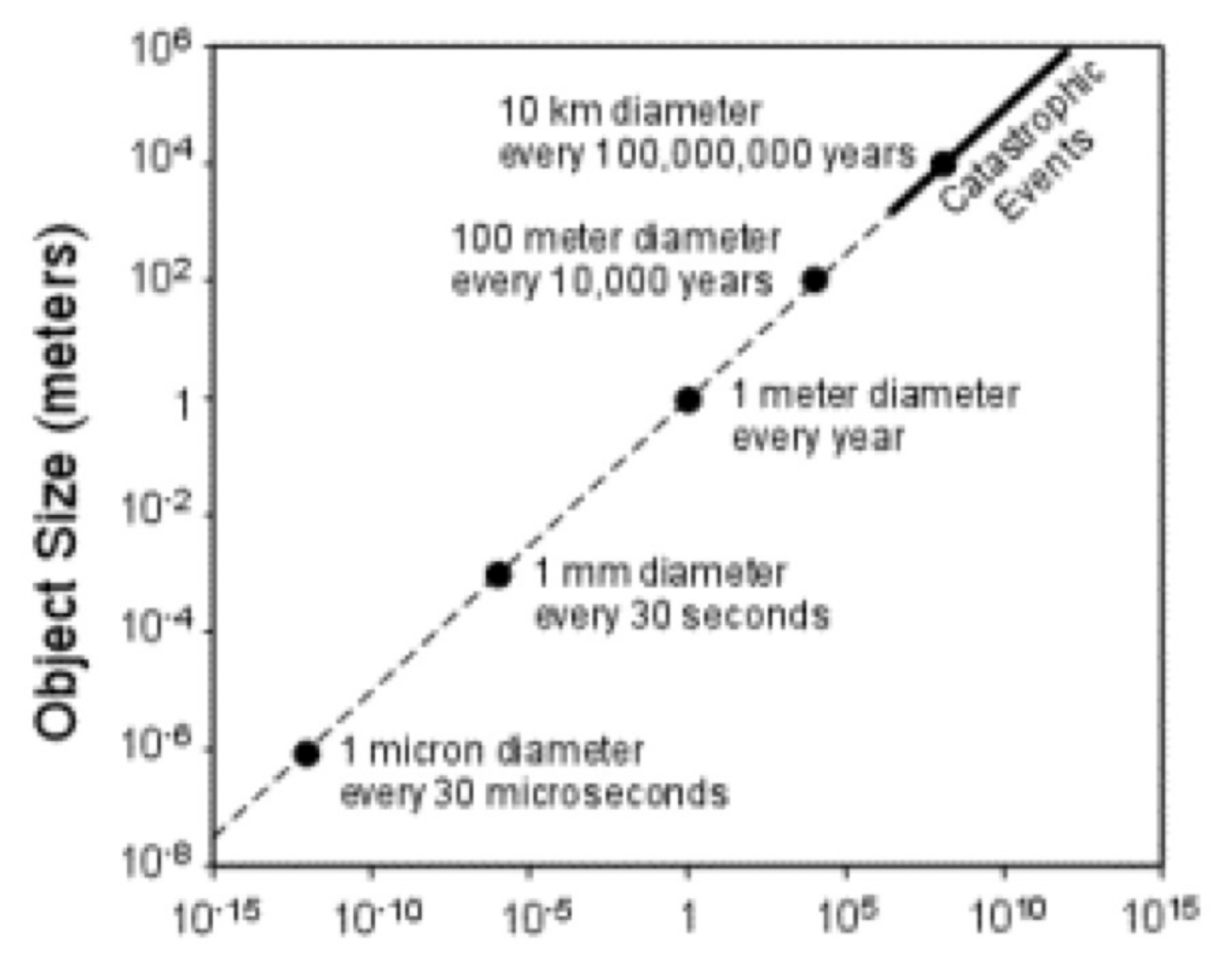
both 290±20 Ma

22 and 32 km

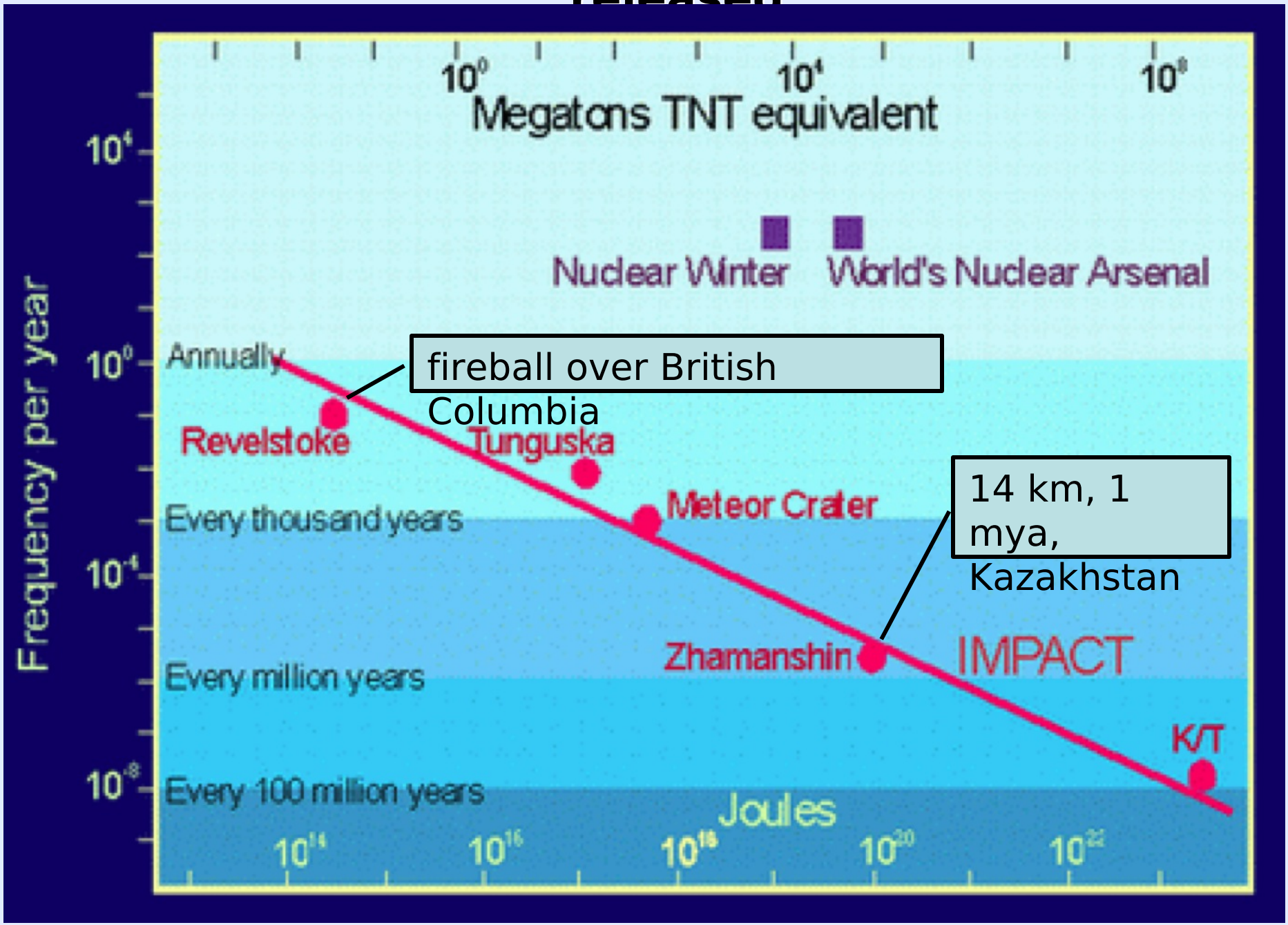
islands show central uplift structure

terrain shows widespread scarring from huge ice sheets, which erased most smaller craters

Average time (yr) between asteroid impacts on Earth



Asteroid impact frequency vs. energy released



To interactively explore an impact crater structure...

http://www.psi.edu/explorecraters/virtualtours.htm

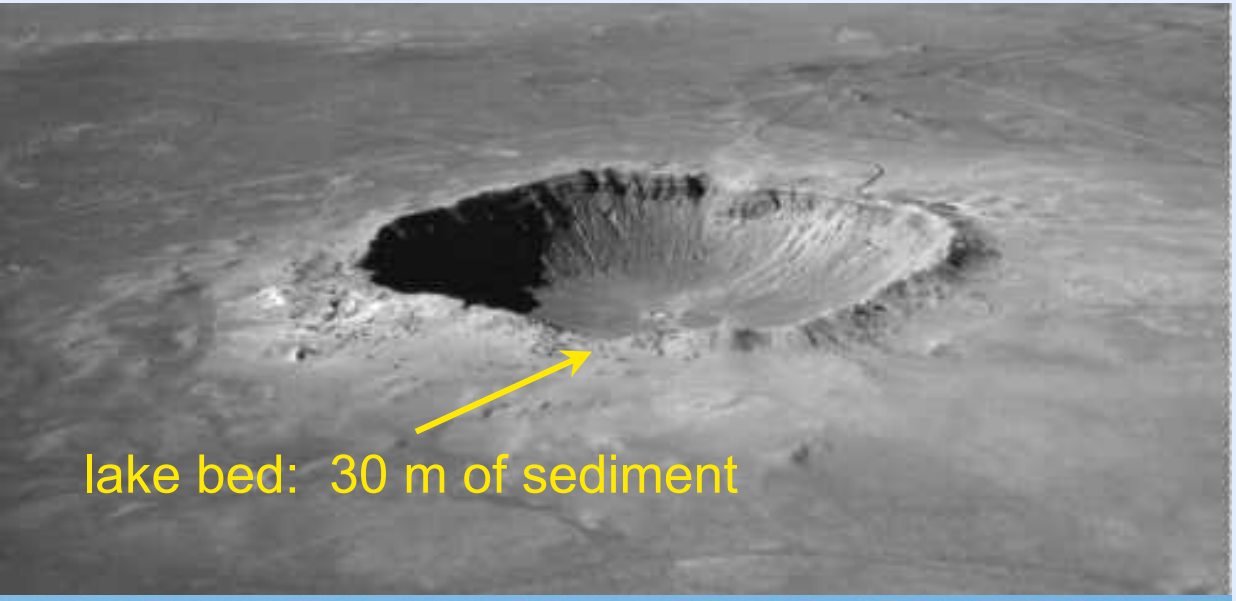
where you can tour:

- Barringer Meteor Crater, Arizona
- Ries Impact Structure, Bavaria
- Haughton Impact Structure, Canada

Barringer & Ries will always be associated with Eugene Shoemaker.

Shoemaker found proof that Ries was an impact crater in stones of town church!!

Barringer Meteorite Crater, Arizona, ~50 Ka



1.5 km wide

180 m deep

rim 50 m high

Meteor:

- 40 m,
- pure Ni-Fe (interior of small planetoid)
- speed: 14-20 km/s
- 150x Hiroshima

When discovered, 15x15 km surrounding area covered with chunks of meteoritic iron (30 tons). Barringer found none by drilling!

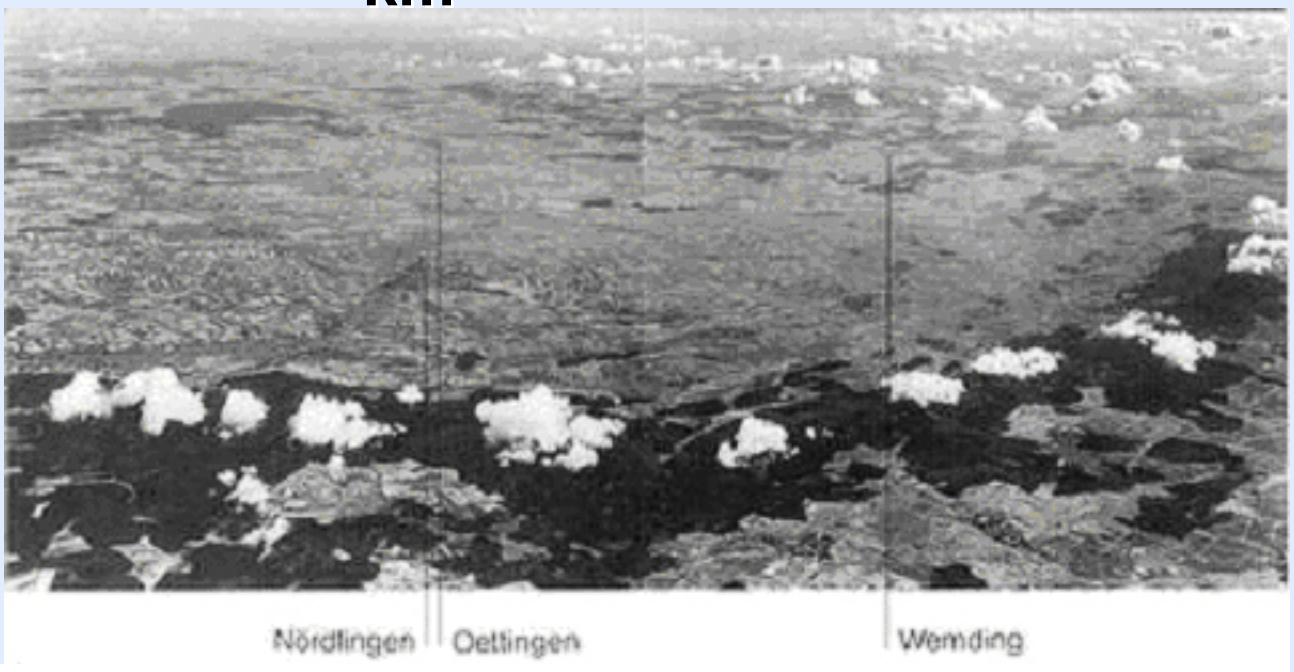
In 1960, Eugene Shoemaker et al. first proved Barringer Crater was of meteor origin by finding coesite

Coesite = high-pressure version of quartz (sandstone)

- not natural
- first method of identifying meteor craters

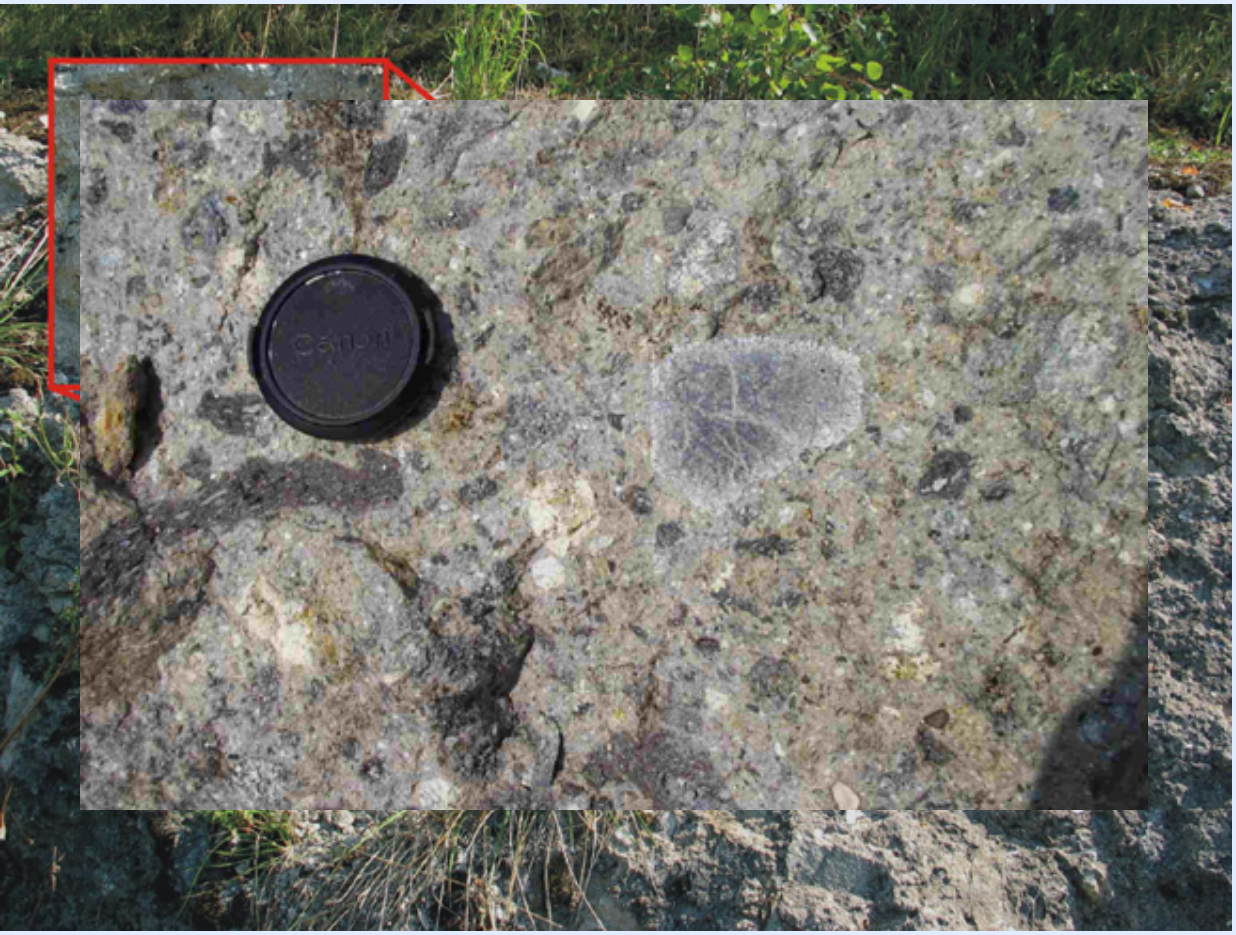
impact breccias at Barringer (a stew of every kind of rock)

Ries impact structure, Bavaria: 14.5 Ma, 24 km



One of best-preserved meteorite impact craters on Earth, but not well exposed; partially filled by sediment, farmland, and forests.

Ries - evidence of impact



Suevites are **impact breccias** that contain fragments of impact **glass**.

At this small roadside outcrop, note black patches of impact glass and abundant white fragments of shocked **gneiss** and **granite**.

Suevites contain rocks excavated from as deep as 2 km by impact!

Shatter cones: rocks shocked by impact

Now instead of waiting for a comet or asteroid to hit us, we send spacecraft missions to them

first mission to collect **comet samples** (+ interstellar dust)

- STARDUST: 2004 flyby of Comet Wild 2
- Capsule soft-landed in Utah, 2006

first controlled **lander** on a comet:

- ROSETTA: comet rendezvous in 2014

first mission to **shoot** a comet

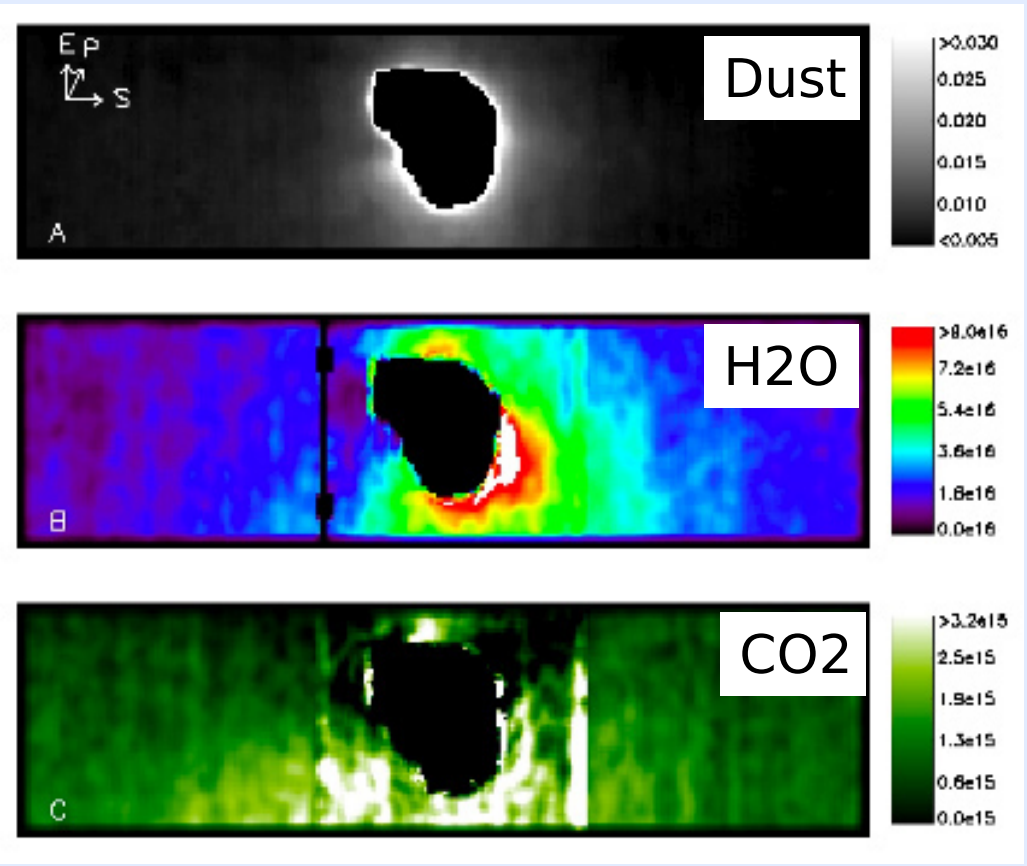
- DEEP IMPACT: Comet Tempel 1 (2005)
- 370 kg copper impactor created a crater to expose fresh material from interior and take spectra of it

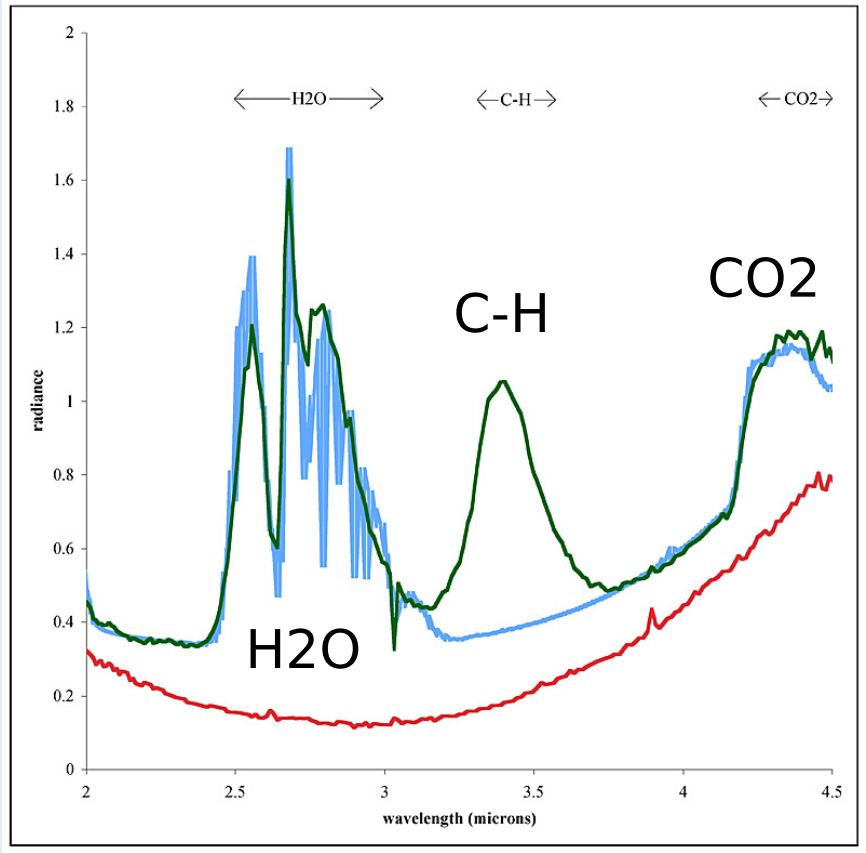
Movie: Comet-DeepImpact-DonYeomans.mov

Deep Impact blasted Comet Tempel 1

Movie: Deep Impact hits comet Tempel (silent).mov

Spectra from Deep Impact blast





Asteroid missions...

NEAR SHOEMAKER (near.jhuapl.edu)

- Launched 1996, orbit of & landing on Asteroid Eros

DAWN (dawn.jpl.nasa.gov)

- Launched 2007, orbit of Vesta (2010) & Ceres (2014)

Hayabusa (www.isas.ac.jp/e/enterp/missions/hayabusa/)

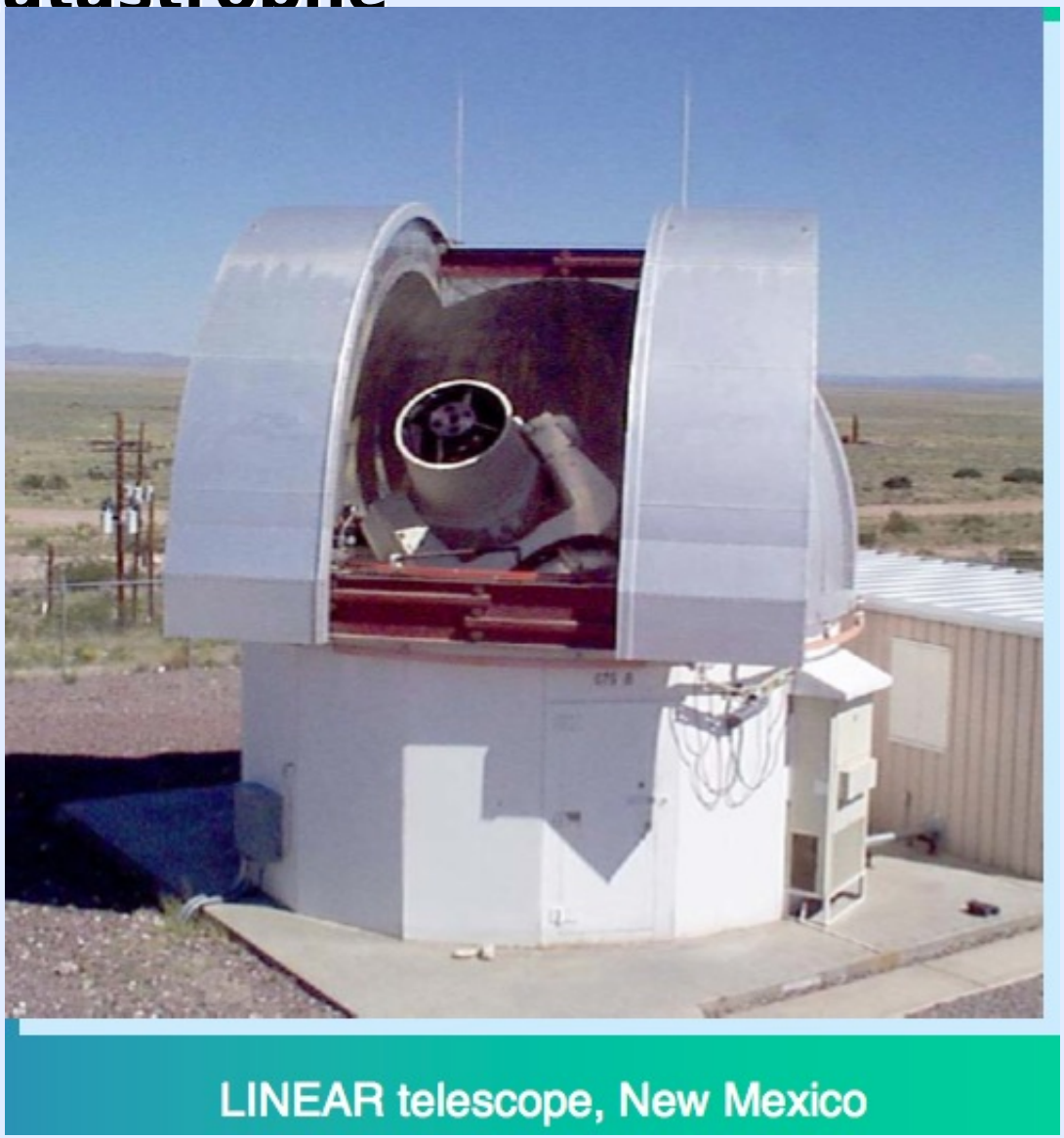
- Launched 2003 , 2005 sample collection from Asteroid 1998 SF36 (return 2007)

Hayabusa: First encounter with sub-km Near Earth Asteroid

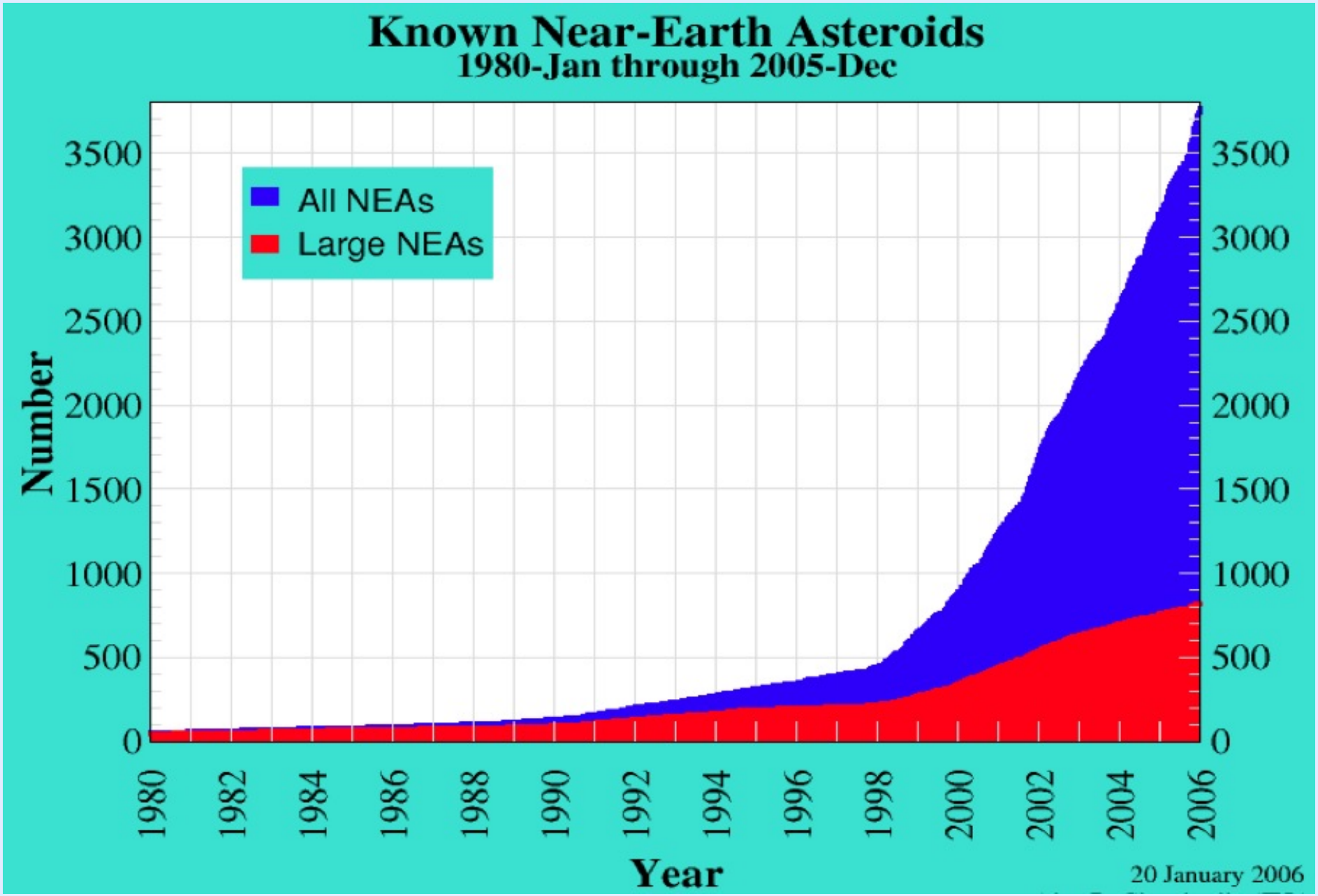
NASA's SpaceGuard Survey to find asteroids that could cause a global catastrophe

- Asteroid orbits permit decades of warning
- Most asteroids are being discovered by 4 small (1-m) telescopes with NASA & USAF support
- Spaceguard Goal : find 90% of NEAs > 1 km diameter by end of 2008

(NEA=Near Earth Asteroid)

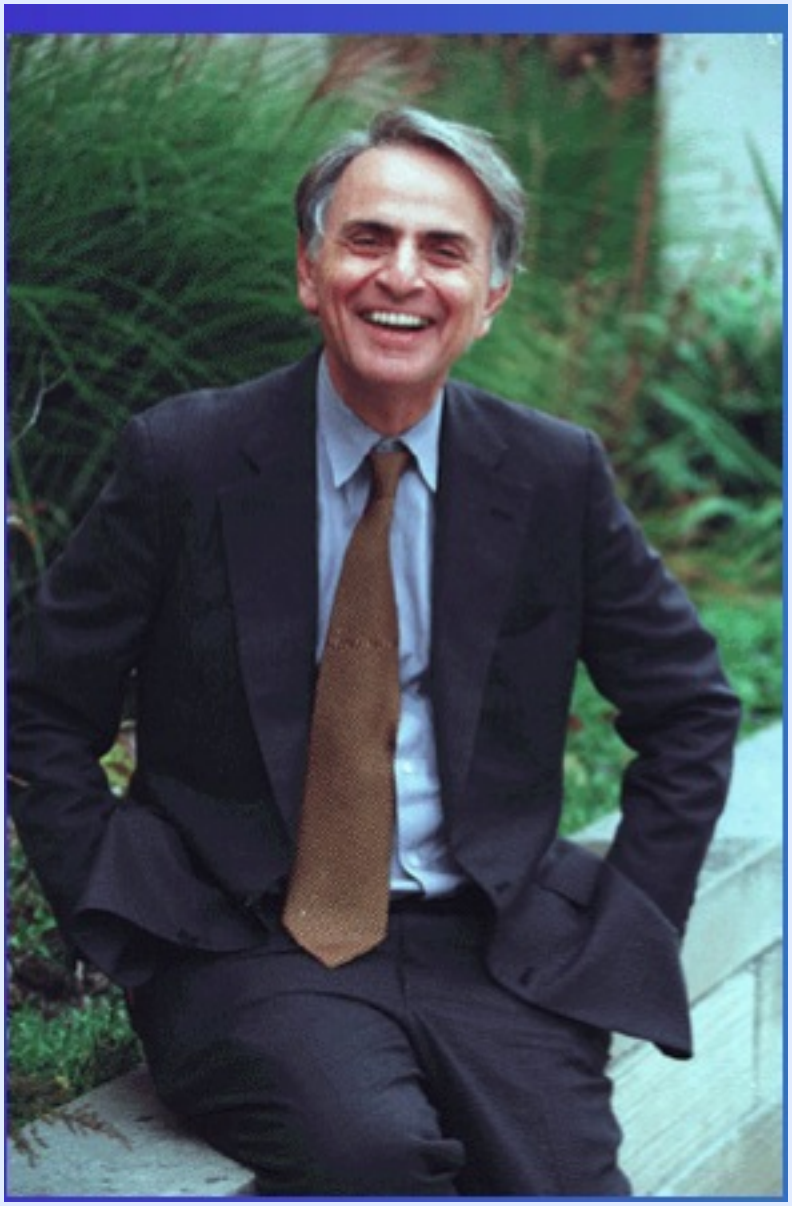


LINEAR telescope, New Mexico


Known Near-Earth Asteroids
1980-Jan through 2005-Dec
All NEAs
Large NEAs
Number
0
500
1000
1500
2000
2500
3000
3500
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
20 January 2006

NASA impact hazard web site

Sagan on Impacts and Civilizations



"Since hazards from asteroids and comets must apply to inhabited planets all over the Galaxy, if there are such, intelligent beings everywhere will have to unify their home worlds politically, leave their planets, and move small nearby worlds around. Their eventual choice, as ours, is spaceflight or extinction."

Pale Blue Dot (1994)

Miracle Planet #1: Violent Past
30:00 to 42:30

How did life survive a 500-km asteroid impact?

(1) Permian bacteria in suspended animation in drops embedded in salt layer in nuclear waste storage

(2) simulation showing Goldilocks Zone 1-2 km down where heat pulse from impact doesn’t kill life

(3) life in 2-mile deep S. African mine